AD NUMBER
AD894547
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 24 MAY 1972. Other requests shall be referred to Aeronautical Systems Div., Wright-Patterson AFB, OH 45433.**
AUTHORITY
ASD ltr 8 Feb 1974

FTC-TR-70-8

CATEGORY II PERFORMANCE AND FLYING QUALITIES TESTS OF THE HH-53C HELICOPTER

WAYNE J. BARBINI
Project Engineer

PAUL J. BALFE
Major, USAF
Project Pilot

CLARK E. LOVRINE, Jr.
Major, USAF
Project Pilot

Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; 24 MAY 1972. Other requests for this document must be referred to

[redacted] of ASD (ASZTH), Wright-Patterson AFB, Ohio 45433.

FOREWORD

This report contains the results of the Category II performance and flying qualities tests of an HH-53C helicopter, USAF S/N 67-14993, conducted at Sikorsky Aircraft Division of United Aircraft Corporation in Stratford Connecticut, from 26 August 1969 to 27 February 1970. Conclusions and recommendations are published herein. Test techniques, data analysis methods, and test data will be published in a Substantiating Document (reference 1) at a later date. The program originated in a letter dated 1 March 1968 in which the Air Force Flight Test Center (AFFTC) was requested by the Aeronautical Systems Division (ASZTH) to conduct the HH-53C Category II test program. The tests were conducted under the authority of AFFTC Project Directive 69-2 with AFFTC priority 25. The program structure was 482A.

Rodney L. Ritter, First Lieutenant, USAF, assisted greatly in reduction and analysis of test data.

Foreign announcement and dissemination by the Defense Documentation Center are not authorized because of technology restrictions of the U.S. Export Control Acts as implemented by AFR 400-10.

Prepared by:

Wayne J. Barbini
WAYNE J. BARBINI
Project Engineer

PAUL J. BALFE
Major, USAF
Project Pilot

CLARK E. LOVRIEN, Jr.
Major, USAF
Project Pilot

Reviewed and Approved by:

1 April 1970

Thomas J. Cecil
THOMAS J. CECIL
Colonel, USAF
Commander, 6512th Test Group

Alton D. Slay
ALTON D. SLAY
Brigadier General, USAF
Commander

evaluating recommendations from testing. In some cases the costs associated with some desirable changes may not be commensurate with the system benefit or with the priority of user requirements. Numerous recommendations contained in this report should be considered in future procurements, if appropriate.

FOR THE COMMANDER

William D. Eastman, Jr.

WILLIAM D. EASTMAN, JR., Lt Col, USAF
Chief, Helicopter Program Office
Directorate of Combat Systems
Deputy for Systems

15. Concur. ASD substantiated the requirement for a Follow-On Evaluation to accomplish several test objectives, including high altitude hover data. AFFTC conducted the tests and reported the results in FTC-TR-71-54 and FTC-TR-72-7.

16 and 17. Concur with intent, but not with recommended action. Because of basic design characteristics of the cruise guide system and known areas of significant inaccuracy, this indicator is not a primary flight instrument. ASD questions the correlation between cruise guide indications and critical loads in the dynamic components. An advancing blade tip machmeter (ABTMM) would provide more useful information to the aircrew in all flight regimes. Such an instrument would be adaptable to any helicopter design, not exclusively the H-53 system. Refer to FTC-TR-71-11 and ASD Addendum. Further ASD action is pending USAF direction and funding based on a user requirement.

18 and 19. Concur with intent. ASD has initiated action to incorporate the required information in the flight manual.

20. Concur. Cursory investigation of flight control system indicates that the costs associated with such changes would not be commensurate with the resulting system improvement. Adequacy of the present aircraft performance envelope for current mission requirements does not justify further investigation of this characteristic.

21. Concur with intent. ASD has incorporated the appropriate information in the flight manual. Sufficient investigation was conducted to determine appropriate aircrew guidance, should this characteristic be encountered. The aircraft operating envelope has been constrained by a tip mach limit to avoid operation expected to produce this phenomena.

GENERAL COMMENT: Procurement of the USAF HH/CH-53B/C was directed "off-the-shelf" with minimum modifications to the existing USMC CH-53A configuration. Directed lead times did not allow normal development procedures to be followed. For example, cockpit mock-up inspection was precluded by the expedited procurement process. Initially no Category II tests were authorized. Deployment to combat prior to adequate testing allowed the operator to accumulate extensive experience in operating the system. Based on this experience, user requirements must be carefully considered in

6. Concur with intent. ASD incorporated a new set of resistors in the warning horn circuit to reduce the sound level. The using command selected the final sound level by operational flight tests to insure satisfactory results of this modification.

7. Do not concur. While lower settings would be satisfactory for approaches and landings in clear areas, the present actuation level is preferable for rescue operations which involve heavily forested and mountainous terrain.

8. Do not concur. ASD has received no adverse comments on this feature from any operational command. Despite the infrequent possibility of door interference, the H-53 cargo area is adequate. Costs associated with the recommended change are not commensurate with the benefit to be derived. This recommendation should be considered in future procurement, if appropriate.

9 and 10. Concur with intent. These and several other cockpit improvement areas are being considered by USAF for modifications in conjunction with additional avionics to satisfy stated user requirements. ASD recommends a development program to accomplish a thorough cockpit redesign, mock-up, and prototype evaluation prior to extensive expenditures to reconfigure the cockpit area. Further action by ASD requires program direction and development funds from Hq USAF.

11. Concur with intent. ASD has reviewed ECP 7445 to raise the interphone control boxes. ASD provided technical approval of the ECP with the recommendation that WRAMA procure the change.

12. Concur with intent. See comments in Paragraphs 9 and 10, above.

13. Concur with intent, but not with recommended action. Investigation revealed that improper filter design caused the problem cited. Incorporation of redesigned filters has eliminated this situation.

14. Concur with intent. ASD obtained ECP 7380R2 to accomplish this change. After several revisions, this ECP was granted technical approval. Pending requirements to incorporate other improvements to the static discharge system, procurement action on this ECP was not accomplished. Final disposition of this recommendation (and ECP) will depend upon user priorities and AFLC funds.

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)

WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433

REPLY TO ATTN OF: ASD/SDQH 5-5 (Maj Thompson/54921/cal/H-53/R&D 9-2)

SUBJECT: ASD Addendum to FTC-TR-70-8, H-53 Performance/Flying Qualities Tests

TO: Recipients of FTC-TR-70-8

This report is a part of and should remain attached to FTC-TR-70-8, "Category II Performance and Flying Qualities Tests of the HH-53C Helicopter". Paragraph numbers below correspond to the recommendations in the AFFTC Technical Report.

1. Concur. However, the data obtained in this program is presented in such a form that further data analysis is an unavoidable requirement in the process of updating the Flight Manual. ASD/SDQH has negotiated a commercial contract to accomplish this task. All other performance data available will be reduced concurrently, to update the entire appendix simultaneously.

2. Do not concur. By direction, the H-53 helicopter was procured "off-the-shelf" with a minimum of changes to adapt for USAF requirements. Five years of operational employment demonstrate that the present AFCS/trim system is adequate for the present "normal" mission. For information, H-53's extensively modified for night recovery operations have incorporated several AFCS improvements to meet more stringent requirements of specialized missions. AFCS improvements are feasible, when requirements are identified. ASD plans no further action pending receipt of requirement, direction and development funding. This recommendation should be considered in future procurement or modification programs, if appropriate.

3. Do not concur. The present T_5 indicating system is in accordance with all applicable USAF requirements. No adverse comment on this feature has been received from any operating command. Maintenance experience has not attributed premature failure or similar problems to the T_5 response characteristic.

4. Concur with intent. New photocell detector units have satisfactorily completed operational evaluation with no false indications. ASD understands that a complete retrofit will result from AFLC procurement of improved detectors.

5. Concur. ASD approved and procured ECP 7207R2 to provide an improved flight engineer's seat with backrest, seat belt, and shoulder harness restraint.

FTC-TR-70-8

(14) AFFTC-TR-70-8

(9) Final rept. 26 Aug 69-27 Feb 70,

(6)

CATEGORY II PERFORMANCE AND FLYING QUALITIES TESTS OF THE HH-53C HELICOPTER.

A
F
F
T
C

(10) WAYNE J. BARBINI,
~~Project Engineer~~

PAUL J. BALFE
[redacted]

CLARK E. LOVRIEN, Jr.
~~Major, USAF~~
Project Pilot

TECHNICAL REPORT No. 70-8

(11) APR[redacted] [redacted]70 (12) 23p.

(16) AFFTC-69-2

[redacted]

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

1473

012 100

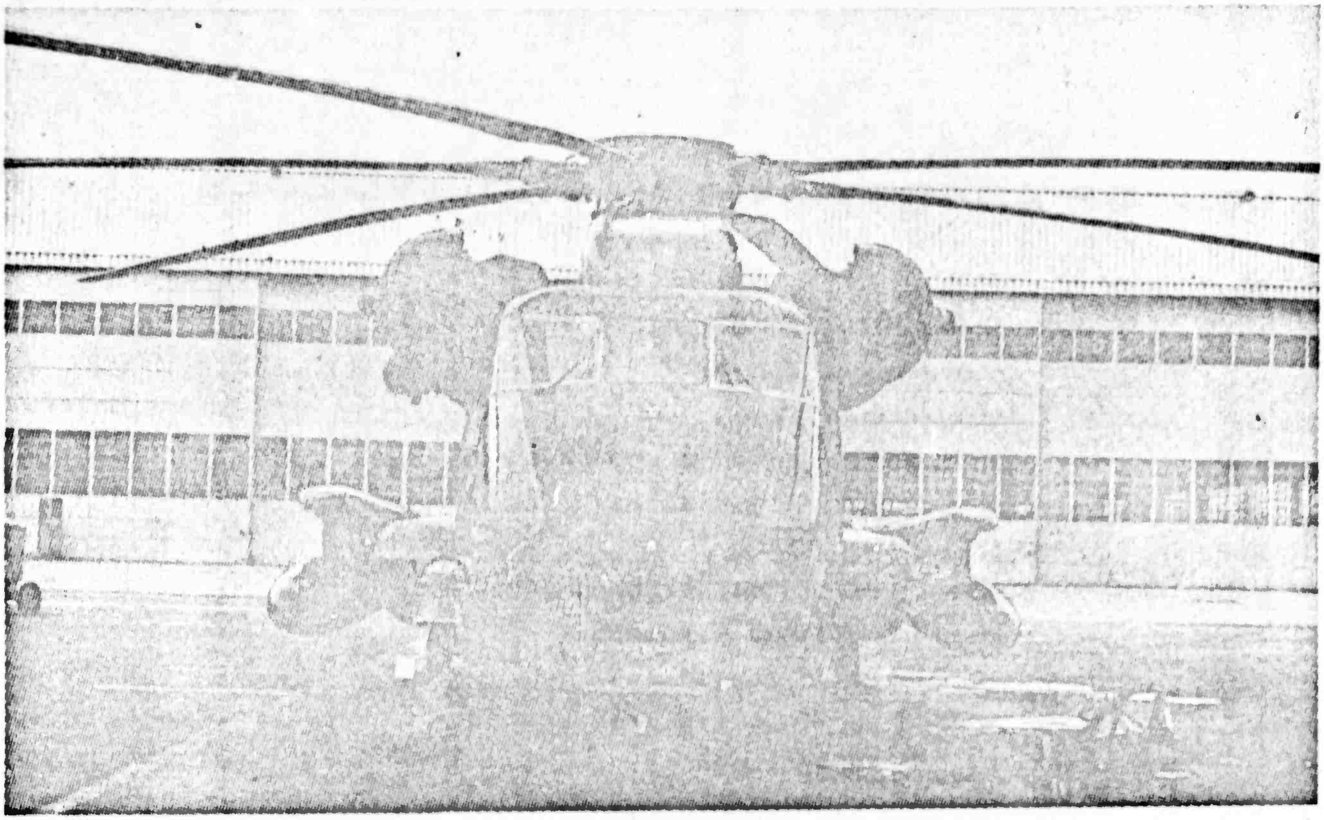
ABSTRACT

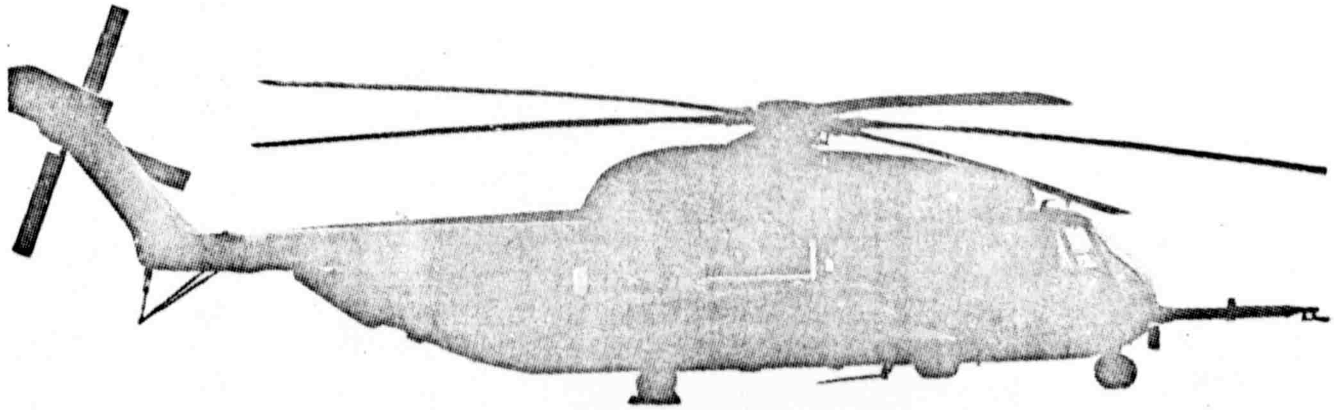
This report presents the results of the HH-53C Category II performance and flying qualities evaluation which was conducted to obtain data for inclusion in the Flight Manual. The Flight Manual power required to hover at various wheel heights was 2 to 7 percent higher than that obtained in this program. The specific range data in the Flight Manual were accurate at the recommended cruise airspeed, but were up to 10 percent higher than test data at the higher airspeeds. During the hover portion of the test program, rotor blade compressibility effects resulted in up to a 5-percent increase in power required. Rotor blade compressibility was most significant during level flight when advancing blade-tip Mach numbers as high as 0.95 were obtained. For given airspeed, altitude, gross weight, and rotor speed, power required increased as much as 38 percent as advancing blade-tip Mach number was varied from 0.76 to 0.94. During level flight below a gross weight of 38,000 pounds and 5,000 feet density altitude, maximum airspeed was limited by either the up collective pitch stop or by the advancing blade-tip Mach number, rather than the aircraft airspeed redline, engine power, or any engine/torque limitations. The HH-53C exhibited positive static stability for all flight conditions except for a neutral or slightly negative longitudinal stability at approximately 35 KCAS for level flight and partial power descent. With the automatic flight control system (AFCS) on, the helicopter was stable about all axes. With the AFCS off, the helicopter was dynamically unstable about all axes in a hover, while in forward flight it was dynamically unstable in pitch and roll with some degree of stability in yaw. The AFCS had insufficient longitudinal authority, requiring cg trim adjustments when the flight conditions were changed. The cyclic stick trim system was unsatisfactory because it was sloppy, slow to operate, and fed back forces while maneuvering, inducing a PIO in pitch and roll.

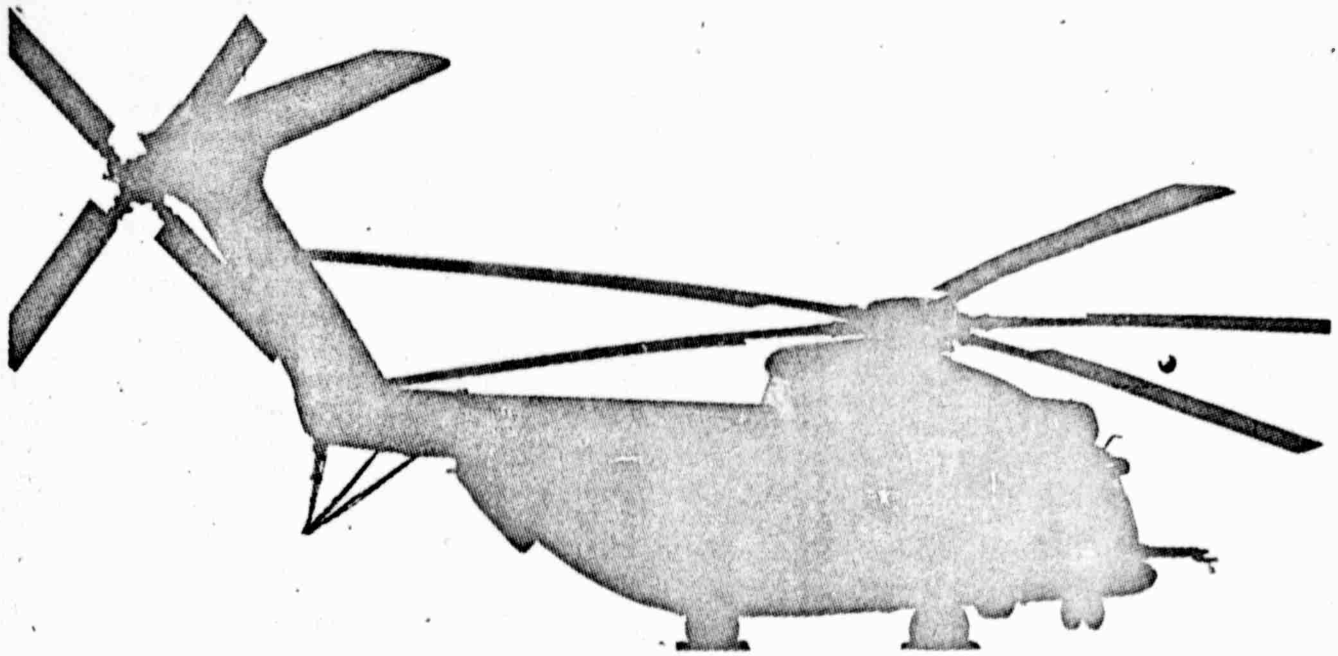
TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND SYMBOLS

Item	Definition	Units
AFCS	automatic flight control system	- - -
AGL	above ground level	- - -
C_T	thrust coefficient	dimensionless
EAPS	engine air particle separator	- - -
IFR	instrument flight rules	- - -
IGE	in ground effect	- - -
KCAS	knots calibrated airspeed	kt
KIAS	knots indicated airspeed	kt
KTAS	knots true airspeed	kt
M_{tip}	advancing blade-tip Mach number	dimensionless
N_1	gas producer speed	percent or rpm
OAT	outside air temperature	- - -
OGE	out of ground effect	- - -
PIO	pilot-induced oscillation	- - -
SHP	shaft horsepower	$550 \frac{\text{ft-lb}}{\text{sec}}$
T_5	power turbine inlet temperature	deg K
σ	solidity ratio	dimensionless
μ	advance ratio	dimensionless







INTRODUCTION

The HH-53C was the third generation of the H-53 model helicopter, the two predecessors being the USMC CH-53A and the USAF HH-53B. The HH-53C was a modified version of the HH-53B with the major changes consisting of modification of the sponsons to a cantilever support for the jettisonable 450-gallon external fuel tanks, and incorporation of the uprated T64-GE-7 engines (3,435 SHP versus 2,850 SHP in the HH-53B). The HH-53C, like the HH-53B, was equipped with an automatic flight control system (AFCS) and an inflight refueling system.

The test program was conducted at Sikorsky Aircraft Division of United Aircraft Corporation in Stratford, Connecticut, from 26 August 1969 to 27 February 1970. Seventy-five flights were made for a total test time of 99 hours.

The test program was to include autorotational height-velocity tests. These tests have not yet been conducted because the contractor had not completed tests which are required to clear the aircraft for that work. Height-velocity tests will be conducted at a later date.

The empty weight of the test helicopter, including test instrumentation, was 25,258 pounds. The cg location was 347.6. This compares with 25,222 pounds and a cg of 344.4 for a production HH-53C. Due to the additional weight of the test instrumentation, the armor plating installed to protect the crew and vital components of the helicopter was removed to allow testing in the entire gross weight range. The test program was conducted with the 450-gallon external fuel tanks installed and, except for two flights to determine the effects on aircraft and engine performance, the engines were not equipped with engine air partial separators (EAPS).

TEST AND EVALUATION

Cockpit Description

Normal crew entry was through the two-piece personnel door in the forward right fuselage. The top half of the door hinged inward at the top and latched against the cabin ceiling, while the bottom half was hinged at the forward edge and opened inward. When the forward cabin area was loaded with bulky cargo, the lower door could not be fully opened. This partial opening restricted crew entry. Once the door was open, a small light step was secured to the floor and hung out the opening to afford a two-step entry into the cargo compartment. The lower door of the CH-53A used by the United States Marine Corps hinged down and out from the lower edge and incorporated steps to aid crew entry. However, a door of this type would interfere with hoist operations. A personnel door should be provided that can be opened in flight, does not restrict hoist operations, and can be opened regardless of the internal cargo. (R 8)[1]

Entry to the cockpit area was by way of a box-like step to the flight deck which was above the cargo floor. Access to the pilots' seats was from the area between the two seats. Forward movement in this center area was blocked by the center console on the floor and the overhead console which was low at the rear and sloped down as it extended forward. Lateral movement from the center area was severely restricted by the "wings" of the armor seat. Limited freedom of movement made entry very difficult with or without a parachute on. The pilots entered by stepping over the lower console and (on the right side) the collective, while contorting the upper body in an attempt to avoid head contact with the overhead console. There were well placed handholds located on the overhead center of each windshield, but their usefulness was restricted because they were hidden behind the Juliet-28 communication boxes protruding from the overhead into the cockpit immediately aft of, and adjacent to, the handholds. These boxes were also frequently hit by the pilots' heads on entry, exit, and during seat adjustments or motions forward in the seat. In that location, these boxes were a safety hazard as well as an encumbrance during entry and exit and should be relocated. These obstructions to entry and exit often resulted in various switches and controls on the overhead panel and engine control quadrant being inadvertently moved from their set positions. When seated, the pilots had difficulty seeing the overhead panel because of its position directly beside and aft of the crewmembers' heads. The armor seat wings on the center side of each seat restricted the view and accessibility of the overhead switches on the rear of the overhead panel. A flight engineer should be available to check and set these switches, yet according to reference 2, the fold-up engineer's seat between and aft of the pilot's and copilot's seats was not to be occupied during takeoffs, landings, or in adverse weather. That seat was very uncomfortable when used more than 30 minutes. A safe, comfortable flight engineer's seat should be provided. (R 9, R 5)

[1] Numbers designated as (R 8), etc., represent the corresponding recommendation numbers as tabulated in the Conclusions and Recommendations section of this report.

The field of view from the cockpit while taxiing was excellent to a point slightly aft of the three and nine o'clock positions from the right and left seats, respectively. While airborne in a hover or on an approach, the pilots' fields of view were from one and eleven o'clock aft to the three and nine o'clock positions. The forward view was blocked by the high instrument panel and nose high attitude. The glide path and landing zone were hidden behind the instrument panel when the helicopter was on final approach and final heading.

When strapped into the seats it was very difficult for the pilots to look to the rear to see the status of the ramp, passengers, or cargo. A simple rear-view mirror should be centrally mounted on the glare shield so the pilots can see the cargo compartment. (R 10)

The pilot's and copilot's interphone control boxes were located low and just forward of the circuit breaker panels on either side. They were so low that the pilots had to lean forward to operate the controls which were difficult to see. The call button was not normally used because it was hard to reach and, under certain conditions, caused interference between the crewmember and the cyclic control. Easy use of the call button was desirable so the crewmember not flying would not have to use the trigger switch on the cyclic control handgrip for intercom transmissions. These interphone boxes should be raised so that the crewmember not flying can use the call button. (R 11)

The location of the OAT gage was unsatisfactory. It was placed above the copilot's windshield and behind the boxes for the Juliet-28 communications equipment. Neither the pilots nor the flight engineer could see the gage from their normal positions because of the Juliet-28 boxes. The copilot had to lean forward and to one side, tilting his head fully back, to see the gage. The pilot and flight engineer could not see it at all from their crew stations. The pilot would be unable to use the gage effectively even if the Juliet-28 boxes were removed as it was located too far from his station laterally. The gage should be relocated near the top of the center windshield to allow all cockpit crew members to see and use it. (R 12)

A fuel filter bypass condition was indicated by a fuel filter bypass light on the advisory panel. On the test aircraft this light was illuminated during all flight conditions. This system should be modified to handle the increased fuel flow of the -7 engines so the light would be meaningful when illuminated. (R 13)

The static discharge system incorporated a static charge high light on the caution panel. Illumination of the light meant either that a high static charge existed on the helicopter or that the system had malfunctioned. When it illuminated it also caused the master caution light in front of each pilot to illuminate. This was very disconcerting as it cycled frequently during hover operations and caused all crewmembers to direct their attention to what could have been (but was not) an indication of a potentially serious situation. If required at all, this light should be on the advisory panel. (R 14)

The turbine inlet temperature (T_5) was indicated in the cockpit on a separate gage for each engine. The system provided such slow response to temperature changes as to be completely valueless in detecting a hot

start or over-temperature condition. During engine start, the engine reached 40-percent N_1 rpm before any sign of a temperature increase was noted, although heat waves from the exhaust could be seen. The engine stabilized at idle rpm for over 1 minute before the temperature increased to the idle temperature range. A temperature indicating system should be provided that gives immediate, accurate temperature indications at all times. (R 3)

The fire warning system used photocell flame detectors which were triggered several times by sunlight. A NOTE to this effect is in the Flight Manual, but this does not stop the crew from directing their attention to the fire lights when they are illuminated. Also, because these detectors "see" flame, excessive temperature would not be detected before an actual fire. The system as installed should be shielded to prevent actuation by sunlight. The existing system is not in accordance with AFCS Design Handbook DH 1-6, Design Note 3M3. A system actuated by high temperature would be more desirable because it would indicate an abnormal situation before the onset of fire and it would not be actuated by sunlight. (R 4)

Ground Handling

The ground handling qualities of the HH-53C were good. Taxi speed was controlled through the use of cyclic control, collective pitch, and brakes, while turns were made by applying the respective directional pedal. The brakes were smooth and effective. The radius of turn was positively controlled by the directional pedals which allowed the pilot to maneuver precisely on a hard, prepared surface.

Hovering Performance

In-ground-effect (IGE) and out-of-ground effect (OGE) hovering performance data were obtained by tethered and free flight techniques at sea level. Tethered hovering was investigated at wheel heights from 5 to 100 feet in less than 3 knots of wind.

For a constant C_T (thrust coefficient) rotor blade compressibility resulted in up to 5-percent increase in power required. The estimated performance figures in the Flight Manual were 2 to 7 percent higher than test data for corresponding tip Mach numbers. Since tethered hovering was conducted at only one pressure altitude, the effect could not be determined for the entire C_T range within the helicopter's capabilities. It is recommended that hover performance be obtained at a high altitude test site to more completely define this effect. The Flight Manual should be changed to incorporate this data. (R 15, R 1)

Level Flight Performance

Level flight performance testing of the HH-53C showed that for constant gross weight, airspeed, and altitude, the power required increased with increasing blade tip Mach number. The most signficant effect encountered during this test program occurred at a C_T/σ of 0.090 when a 38-percent increase in power was required as M_{tip} was varied from 0.76 to 0.94 at the same μ. The estimated specific range data in the Flight Manual were accurate at the recommended cruise airspeeds, but at the higher airspeeds the estimated data were up to 10 percent high. It is recommended that the Flight Manual be updated to incorporate these results. (R 1)

The level flight tests were conducted at gross weights from 29,000 to 42,000 pounds, pressure altitude from sea level to 18,000 feet, and rotor speeds from 176 to 200 rpm. Throughout the flight test program the helicopter was limited to an advancing blade-tip Mach number of 0.95. This limit was imposed on the aircraft after the contractor experienced a widening of the tip path plane at high tip Mach number (0.96 to 0.98). This widening of the tip path plane was theoretically caused by the movement of the aerodynamic center of lift at the higher tip Mach numbers, resulting in a rotor blade pitching moment causing dynamic twist. Residual motion during the following revolution allowed a different angle of attack and therefore different twist and resulting flapping path. This phenomenon should be discussed in the Flight Manual and this characteristic should be fully investigated to insure that no undue fatigue stresses result from operation at high tip Mach number. (R 21)

During the level flight tests at gross weights of less than about 38,000 pounds and density altitudes below approximately 5,000 feet, maximum airspeed was limited by the up collective pitch stop when not limited by tip Mach number. Under these conditions in forward flight, performance was limited by control available and not the aircraft airspeed redline, cruise guide indicator redline, engine torque, gas producer N_1 speed, or T_5 limit. This characteristic does not conform to the requirement of paragraph 3.2.1 of MIL-H-8501A (reference 3). This problem should be discussed in the Flight Characteristic Section of the Flight Manual. An investigation should be conducted to correct this deficiency. (R 19, R 20)

Level flight tests to determine the drag penalty of extended landing gear were conducted at a C_T/σ of 0.080. With all flight conditions held constant, there was a 6.6-percent decrease in range with an 8-percent increase in power required at the recommended cruise airspeed.

During the level flight portion of the test program a limited evaluation was conducted with both engines equipped with engine air particle separators (EAPS) to determine the effects on performance. The EAPS was designed to remove foreign particles from the engine inlet air. For the condition investigated with the EAPS installed, power-required increased as much as 9 percent. A typical EAPS installation is shown in figure 1; figure 2 shows the helicopter not so equipped.

Cruise Guide and Pushrod Indicators

The test helicopter was equipped with two instruments that gave indications (from 0 to 100 percent) of the stress/strain at the aft lateral servo on the rotor head. One instrument was the standard cruise guide indicator and the other a test instrument called a pushrod indicator. The pick-off points for the two instruments were separate, but in the same general location. The cruise guide was indicative of the degree of blade stall as measured by vibratory loads on the aft lateral servo. The pushrod indicator was a measurement of the load on the pitch change rod when at the position adjacent to the aft lateral servo. Conditions of high gross weight, high airspeed, high altitude, and low rotor rpm all contribute to the onset of blade stall. There are conditions, primarily high gross weight and high altitude, when the cruise guide received cancelling signals and indicated considerably less (about one-half) than should have been displayed. Under these conditions the pushrod indicator indicated properly and was used as the primary indication

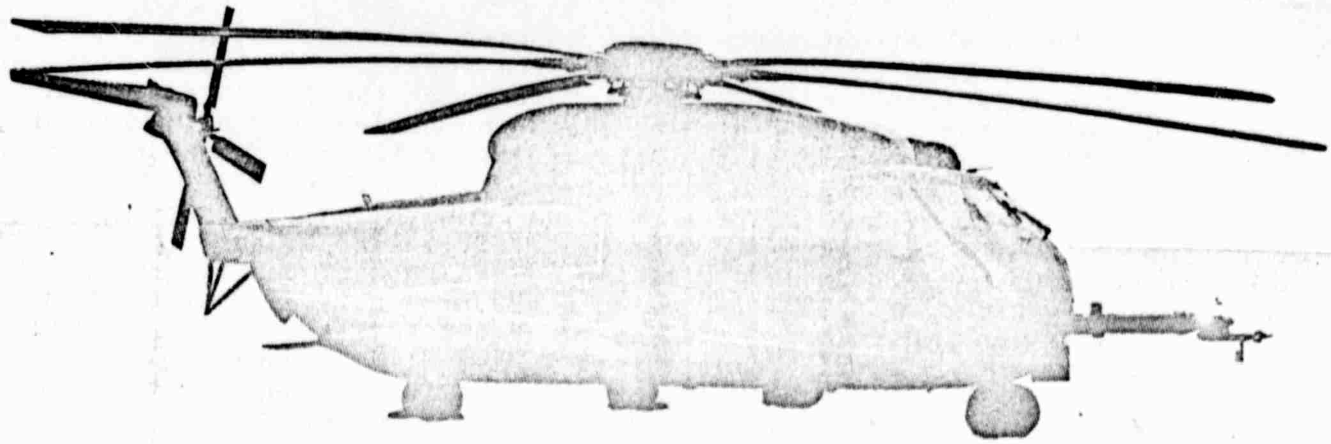


Figure 1

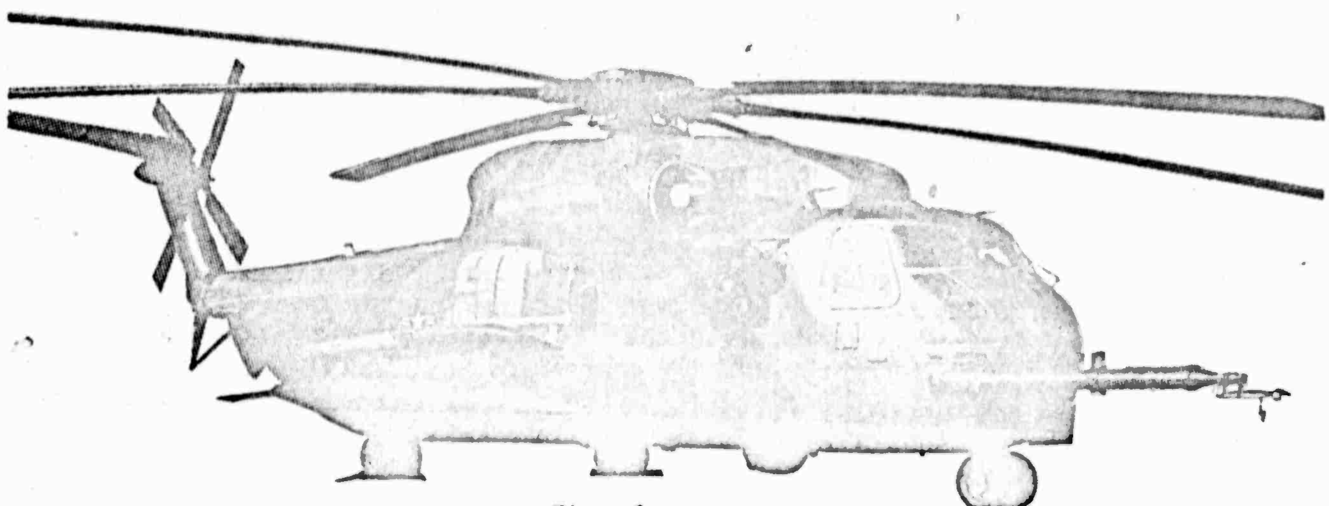


Figure 2

of load limits. However, under more normal conditions, below about 10,000 ft, the cruise guide indicated properly and was used as the primary instrument. The cruise guide indicator was a valuable instrument to the pilot. A similar instrument should be incorporated in all helicopters. Correction factors should be developed and incorporated in the HH-53C Pilots Flight Crew Checklist to allow determination of high altitude limits in flight. (R 16, R 17)

Airspeed Calibration

The aircraft standard airspeed system and the test boom airspeed system were calibrated throughout the airspeed range during level flight. A ground speed course was used and the test was conducted at 30,500 pounds gross weight, 185-rpm rotor speed, mid cg and a density altitude of sea level. The position error values shown in reference 2 for the standard airspeed system agreed with results obtained during this test program.

Static Longitudinal Stability

Static longitudinal speed stability was determined with cg's at stations 328 (fwd) and 352 (aft) with gross weight and density altitude, respectively, varied from 31,000 to 41,000 pounds and 5,000 to 15,000 feet. Flight regimes investigated were level flight, climb, partial power descent, and autorotation. The conditions investigated were representative of the Flight Manual envelope. In general, the static longitudinal speed stability characteristics were satisfactory for the areas investigated. Longitudinal static stability was evaluated by analyzing speed stability characteristics about a trim airspeed.

Neutral or slightly negative speed stability existed around the 35-knot trim point for both level flight and partial power descent. The reversal was not readily apparent to the pilot, but may cause some difficulty in maintaining a constant airspeed in this area. The curve of stick position versus airspeed is essentially positive for all other flight regimes and airspeeds.

The longitudinal control position moves forward about 2 inches as the cg is changed from station 328 to 352. These changes in cg position did not adversely change the stability characteristics of the helicopter for any of the conditions investigated. Speed stability was essentially the same with the AFCS operative and inoperative and for both forward and aft cg locations.

Static Directional Stability

Static directional stability was determined for the same flight regimes as the static longitudinal speed stability but was obtained at only the aft cg limit. Static directional stability was evaluated at a constant airspeed. In conducting this test, the aircraft was trimmed in stabilized flight at zero sideslip angle, and then the sideslip angle was increased by opposite use of lateral stick and directional pedals while maintaining a constant airspeed. This was done for both right and left sideslips. The HH-53C exhibited positive static directional stability for all the flight conditions investigated.

Sideward and Rearward Flight

The helicopter was flown sideward and rearward at 41,000 pounds gross weight with a forward cg. Directional control in sideward flight was satisfactory with a minimum of 8-percent directional pedal travel remaining at 35 KTAS.

Sideward flight to the left and right was satisfactory. Below 15 KTAS, smooth and steady flight was possible. Between 15 and 25 KTAS (translational flight regime), the aircraft tended to "balloon" in altitude and directional control was difficult, being more difficult when in left sideward flight than right. Above 25 KTAS, smooth and steady flight was again possible. Control power was adequate to control direction, but altitude and attitude control required numerous collective and cyclic inputs when flying between 15 and 25 KTAS.

Sideward flight was evaluated at speeds to 35 KTAS while yawed as much as 45 degrees. The yaw was introduced in a direction opposite to

that being flown in order to effect the greatest possible tail rotor "masking". No tail rotor vibrations were noticed nor was there any apparent change in directional pedal response or requirement.

Rearward flight at airspeeds from hover to 32 KTAS was satisfactory. Directional control was adequate and steady flight was possible with minimum cyclic and collective inputs required to maintain attitude and altitude. At translational flight speeds (15 to 25 KTAS) a reduction in collective was necessary to maintain altitude. At the same time a one-inch smooth aft cyclic input was required to prevent nose down pitching.

When in rearward flight at 25 KTAS, a slight nose down movement was initiated to slow the rearward acceleration. The nose down motion continued without further cyclic input, and full aft cyclic was not sufficient to bring the nose up to again accelerate rearward. Without allowing the initial nose down movement to start, rearward flight was possible to 32 KTAS with approximately 17 percent of aft cyclic travel remaining. In recovering from rearward flight, the nose was lowered slightly to slow down and, at about 15 KTAS, a turn to the right was started with the directional pedals. This resulted in a roll to the left and full right cyclic control was just sufficient to stop this, but not enough to initiate a roll back to the right.

These two instances may indicate that the control power available when the cyclic stick was near the aft limit was low, and precision hovering downwind in strong, gusty winds may be very difficult.

Dynamic Stability

The dynamic stability was investigated under various conditions of aircraft speed, cg, weight, and flight condition. With the AFCS on, the helicopter was stable about all axes in all instances. With the AFCS off, the helicopter was dynamically unstable about all axes in a hover. In forward flight it was dynamically unstable in pitch and roll, but displayed some degree of stability in yaw.

The degree of instability in pitch and roll was such that high rates of pitch and roll were experienced within two seconds after control inputs of less than one half inch. Immediate corrective action was necessary to prevent severe and dangerous attitudes from developing.

Automatic Flight Control System

The longitudinal authority of the AFCS was exceeded many times during the tests because it did not have the capability of "following" cyclic movements made in response to power changes. With the AFCS indicator in the ON-ON mode and the pitch channel indices centered in a hover, climb power application required a forward cyclic control input (to maintain the proper attitude) which exceeded the limits of the AFCS. Without resetting the trim wheels the helicopter was flown with essentially no AFCS stabilization in the pitch axis. This required that the cg trim wheels had to be reset to move the pitch indices back into the realm of AFCS stabilization. This was an unsatisfactory situation in that it diverted the pilot's attention to the AFCS indicator and the cg trim wheels. Also, when the cg trim was adjusted, cyclic stick readjustment by the pilot was required to maintain the desired pitch attitude.

A cg trim adjustment was needed again when in cruise to insure that AFCS limits would not be exceeded during maneuvering. At high speed, 140 KIAS or more, a power reduction and the associated pitch changes resulted in a loss of AFCS influence to help stabilize and maintain attitude and airspeed.

Flight with the AFCS off was possible with normal control forces but lacked the stability in all axes normally offered by the AFCS. The action of the helicopter was a "wallowing" motion, divergent in pitch and roll, which required constant attention and constant small cyclic inputs to maintain a desired attitude. Flight under these conditions was considerably more fatiguing than with the AFCS on. Extended IFR flight would be extremely difficult because so much attention was required just to fly the helicopter.

Flight with the AFCS servos off was difficult and fatiguing. Forces of 30 to 50 pounds were required to move the cyclic. These forces, coupled with the AFCS-off instability and associated cyclic movements, made flying the helicopter through an approach and landing a difficult and fatiguing task.

The cyclic stick trim system was slow to operate, had excessive slop, and fed forces back to the pilot during maneuvers and during the small control displacements used to make minor aircraft attitude adjustments. Two methods of resetting the trim were provided, a thumb button on the cyclic stick that recentered the trim around the stick position when the button was depressed, and a four-way "Coolie hat" switch on the top of the cyclic stick that was used as a conventional aircraft trim control. The thumb button released the trim immediately, but the trim required one to two seconds to recenter at the new cyclic stick position. The four-way trim system was objectionably slow, usually requiring 4 to 5 seconds before any trimming occurred. In the lateral direction, the aircraft usually rolled 1 to 2 degrees in the opposite direction before the proper action took place. The cyclic stick centering of the trim system was poor. Stick movements within the centering envelope were possible without encountering the trim force gradient. These stick movements resulted in corresponding aircraft movements. The most objectionable deficiency of the cyclic stick lateral force trim system was the feedback encountered when the cyclic was moved against the trim to maneuver the helicopter. After the helicopter attitude started to change, the AFCS/trim system applied additional force (over the normal trim gradient) to the cyclic stick against the input from the pilot in an attempt to return the cyclic stick to the trim position. This resulted in a varying stick force, and, at high airspeeds, produced an objectionable, lateral pilot-induced oscillation which made precise aircraft control very difficult. An improved AFCS/trim system should be provided to eliminate these deficiencies. (R 2)

Landings and Autorotations

Running landings were made on a paved surface. Because of the long tailboom, the touchdown attitude had to be less than 10 degrees nose up to avoid tail-to-ground contact. A high flare was required to slow the aircraft. Under conditions of low excess power available, such as heavyweight-high altitude or single engine flight, high touchdown speeds (in excess of 20 KTAS) were required to prevent a hard touchdown. This was most critical with an aft cg as the hover attitude was 7 to 8 degrees

nose up and little deceleration was obtained once the flare was reduced for touchdown. The high touchdown speed required a large, prepared surface for actual running landings.

The tail low warning system was not satisfactory. The system was designed to be activated whenever the radar altimeter read less than 150 feet and the pilots' attitude indicator indicated more than 10 degrees nose up. The tolerances of the attitude indicator allowed the warning to sound with nose up attitudes as low as 8 degrees. The hover attitude with an aft cg was nearly 7 degrees, and the tail low warning sounded intermittently when hovering in this configuration. The warning horn also sounded almost continuously throughout the last 150 feet of all normal approaches, since the nose must be raised at least 10 degrees to slow the helicopter to zero airspeed. This warning system lost much of its effectiveness by being activated too soon. At only 40 feet above the ground the fuselage angle had to be 68 degrees nose up before the tail would hit the ground, so a warning at 150 feet was a useless nuisance. The warning horn was too loud and prevented effective communication, either between crewmembers and the pilot or between the pilot and ground radio stations. The tail low warning system should be redesigned to reduce the noise level of the warning horn, and to activate the system at 25 feet rather than 150 feet. (R 6, R 7)

The autorotational airspeed for minimum rate of descent obtained during this test program agreed with the published airspeed in the Flight Manual. The aircraft attitude in autorotation was comfortable, but the length of the helicopter and high rates of descent dictated a rapid flare starting at about 150 feet AGL in order to slow the forward speed and arrest the descent rate. No more speed could be lost after the flare because ground contact was imminent. Also, effect of the landing attitude on ground speed was at best neutral and under some conditions (aft cg) caused speed to increase slightly before touchdown. Because of the high flare required to slow further and the inability to touch down at an attitude of greater than 10 degrees nose up, a high touchdown speed was unavoidable (30 KTAS or more).

The Flight Manual discussions of running landings and autorotations should be expanded to include a statement that under condition of low excess power or during autorotations, high touchdown speeds (30 KTAS or more) should be expected. (R 18)

CONCLUSIONS AND RECOMMENDATIONS

The helicopter exhibited good low altitude hover performance and was capable of high forward speeds. The deficiencies of the AFCS/trim system degraded the operational use of the aircraft. Flight with the AFCS off was possible, but was considerably more fatiguing than with the AFCS on.

The hover and cruise data obtained in this test program are considered characteristic of the HH-53C series helicopter.

1. The hover and cruise data obtained in this program should be incorporated into the Flight Manual (page 4).

The longitudinal authority of the AFCS was consistently exceeded because it did not have the capability of "following" cyclic movements made in response to power changes. Constant attention had to be given to pitch control, or cg trim wheels had to be set to move the pitch channel indices back into the realm of AFCS control. This was an unsatisfactory situation in that it required the pilots to devote excessive attention to the AFCS indicator and the cg trim wheels.

The cyclic stick trim system was slow to operate, had excessive slop, and fed forces back to the pilot during maneuvers and small control displacements. Two methods of resetting the trim were provided. The thumb button released the trim immediately, but the trim required 1 to 2 seconds to recenter at the new cyclic position.

The four-way trim system was objectionably slow, usually requiring 4 to 5 seconds before any trimming occurred, and in the lateral direction the aircraft usually rolled approximately 2 degrees in the opposite direction before the proper action took place. The most objectionable deficiency of the cyclic stick force trim system was the feedback encountered when the cyclic was moved against the trim to maneuver the helicopter.

2. An improved AFCS/trim system should be provided to eliminate these deficiencies (page 9).

The turbine inlet temperature (T_5) was indicated in the cockpit by a system that provided such slow response to temperature changes as to be completely useless in detecting or preventing a hot start or overtemperature condition.

3. A system should be provided that would instantaneously show the engine temperature conditions so the crew can detect abnormal conditions and prevent a hot start (page 4).

The fire warning system used photocell flame detectors which were triggered several times by sunlight. This system is undesirable because these detectors "see" flame and a situation of excessive temperature would not be detected before an actual fire.

4. The system, as installed, should be shielded to prevent actuation by sunlight. A system actuated by high temperature would be more desirable because it would indicate an abnormal situation before the onset of fire and would not be actuated by sunlight (page 4).

The flight engineer's seat was between and aft of the pilot's and copilot's seats and was not to be occupied during takeoff and landings. It was very uncomfortable when used more than 30 minutes.

5. A safe, comfortable flight engineer's seat should be provided (page 2).

The tail low warning system was not satisfactory. The system was actuated whenever there was an indication of 8 degrees or more nose up at about 150 feet AGL. During normal approaches the warning horn sounded continuously, since the nose had to be raised more than 7 degrees to slow to zero airspeed. The warning horn was too loud and prevented effective communication.

6. The tail low warning system should be redesigned to reduce the noise level of the warning horn (page 10).

7. This system should be actuated at 25 feet rather than 150 feet ACL (page 10).

For various loads with bulky cargo, the lower door could not be opened far enough to permit unrestricted crew entry.

8. A personnel door should be provided that can be opened in flight, does not restrict hoist operations, and can be opened regardless of internal cargo (page 2).

There were well placed handholds located on the overhead center of each windshield, but their usefulness was restricted because they were hidden behind the Juliet-28 communication boxes protruding from the overhead into the cockpit immediately aft of, and adjacent to the handholds. These boxes were also frequently hit by the pilots' heads on entry, exit, and during seat adjustments or forward motions in the seat. In their present location these boxes were a safety hazard as well as an encumbrance during entry and exit.

9. The Juliet-28 communication boxes should be relocated (page 2).

When strapped in their seats, it was very difficult for the pilots to look to the rear to see the ramp, passengers, or cargo.

10. A single rear-view mirror should be centrally mounted on the glare shield to let the pilots see the cargo compartment (page 3).

The pilot's and copilot's interphone control boxes required leaning forward to operate and were difficult to see. The call button was not normally used because the cyclic control was in the way.

11. The interphone boxes should be raised so the crew member not flying can use the call button and not have to use the trigger switch on the cyclic control for intercom transmissions (page 3).

The position of the OAT gage above the copilot's windshield and behind the boxes for the Juliet-28 communication equipment was unsatisfactory. Neither pilot nor flight engineer could see the gage from his normal position.

12. The OAT gage should be relocated near the top of the center windshield to allow all cockpit crew members to see and use it (page 3).

The fuel filter bypass light on the advisory panel was illuminated during all flight conditions.

13. This system should be modified to handle the increased fuel flow of the -7 engines (page 3).

The static discharge system incorporated a static charge high light on the caution panel. When it illuminated it also caused the master caution light in front of each pilot to illuminate. This was very disconcerting, as it cycled frequently during hover operations and caused all crewmembers to direct their attention to what could have been (but was not) an indication of a potentially serious situation.

14. This light should be on the advisory panel (page 3).

Rotor blade compressibility was encountered and partially defined during the hover portion of the test program. Since hovering was conducted only at sea level, the overall effects could not be completely determined within the capabilities of the helicopter.

15. It is recommended that hover performance be obtained at a high altitude test site to define this effect completely (page 4).

Under normal conditions the cruise guide indicated properly and was a valuable instrument to the pilot, but under conditions of high gross weight and high altitude the cruise guide indicated considerably less than should have been displayed.

16. A similar instrument should be incorporated in all helicopters (page 6).

17. Correction factors should be developed and incorporated in the HH-53C Pilot's Flight Crew Checklist to allow determination of high altitude limits in flight (page 6).

The length of the helicopter and high rates of descent during autorotation dictated a rapid flare starting at about 150 feet AGL in order to slow the forward speed and arrest the descent rate. Because of the high flare required to slow further, and the inability to touch down at an attitude greater than 10 degrees nose up, a high touchdown speed was unavoidable.

18. The Flight Manual discussions of running landings and autorotations should be expanded to include a statement that under condition of low excess power or during autorotations, high touchdown speeds (30 KTAS or more) should be expected (page 10).

During the level flight tests at gross weights of less than about 38,000 pounds and density altitudes below approximately 5,000 feet, maximum airspeed was limited by the up collective pitch stop, when it was not first limited by tip Mach number. The aerodynamic results on the main rotor system at high tip Mach numbers caused a widening of the tip path plane. There is no discussion of the phenomenon in the Flight Manual. This characteristic should be investigated to determine if any undue fatigue stresses will result from operation in close proximity to the limit tip Mach number.

19. The fact that the maximum airspeed may be limited by the up collective pitch stop should be discussed in the Flight Characteristics Section of the Flight Manual (page 5).

20. An investigation should be conducted to determine the feasibility of obtaining more up collective pitch range (page 5).

21. Widening of the tip path plane should be discussed in the Flight Manual and this characteristic should be fully investigated to insure that no undue fatigue stresses will result when operating at high tip Mach number (page 5).

REFERENCES

1. Barbini, Wayne J., Balfe, Paul J., Major USAF, Lovrien, Clark E. Jr., Major USAF, Category II Performance and Flying Qualities Tests of the HH-53C Helicopter, FTC-SD-70-8, Air Force Flight Test Center, to be published.

2. Flight Manual USAF Series HH-53B, HH-53C Helicopter, T.O. 1H-53(H) B-1, 19 August 1968, changed 29 October 1968.

3. Military Specification, MIL-H-8501A, 3 April 1962.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Flight Test Center Edwards AFB, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

Category II Performance and Flying Qualities Tests of the HH-53C Helicopter

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final

5. AUTHOR(S) (First name, middle initial, last name)

Wayne J. Barbini
Paul J. Balfe, Major USAF
Clark E. Lovrien, Major USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1970	14	3

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. AFFTC Project Directive 69-2	FTC-TR-70-8
c. Program Structure ~~482A~~	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	N/A

10. DISTRIBUTION STATEMENT This [redacted]

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	6512th Test Group Edwards AFB, California

13. ABSTRACT HH-53C Category II evaluation to obtain data for the Flight Manual. The Flight Manual power required to hover was 2 to 7% ~~percent~~ higher than test data. Flight Manual specific range data were accurate at recommended cruise, but were up to 10% ~~percent~~ higher than test data at the higher airspeeds. Rotor blade compressibility effects resulted in up to a 5% ~~percent~~ increase in power required. Rotor blade compressibility was most significant during level flight when advancing blade-tip Mach numbers as high as 0.95 were obtained. Power required increased as much as 38% ~~percent~~ as advancing blade-tip Mach number was varied from 0.76 to 0.94. During level flight (below 38,000 pounds and 5,000 feet density altitude), maximum airspeed was limited by either the up collective pitch stop or by the advancing blade-tip Mach number, rather than the aircraft airspeed redline, engine power, or any engine/torque limitations. The HH-53C exhibited positive static stability for all flight conditions except for a neutral or slightly negative longitudinal stability at approximately 35 KCAS for level flight and partial power descent. With the automatic flight control system (AFCS) on, it was stable about all axes. With the AFCS off, it was dynamically unstable about all axes in a hover, while in forward flight it was dynamically unstable in pitch and roll with some degree of stability in yaw. The AFCS had insufficient longitudinal authority, requiring cg trim adjustments when the flight conditions were changed. The cyclic stick trim system was unsatisfactory because it was sloppy, slow to operate, and fed back forces while maneuvering, inducing a PIO in pitch and roll.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
HH-53C Helicopter performance and flying qualities tests hover power compressibility specific range collective pitch stop (up) automatic flight control system cyclic control stick trim adjustment						